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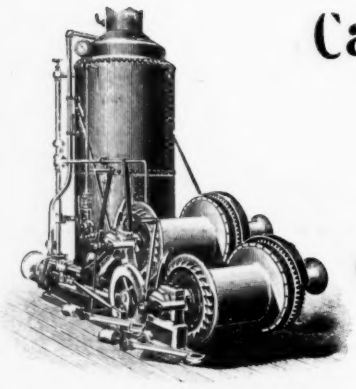

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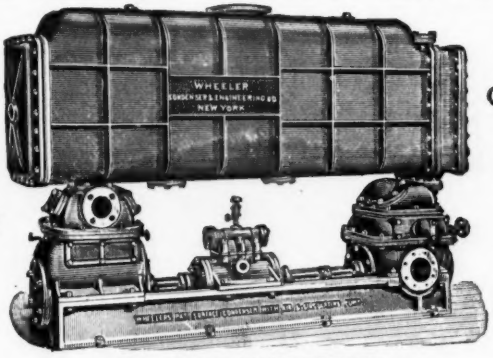

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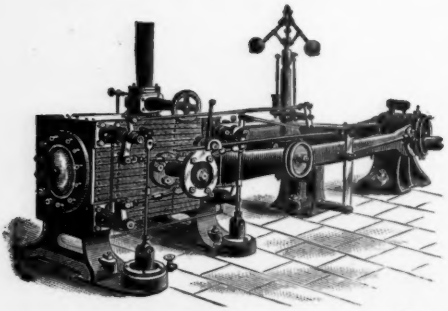

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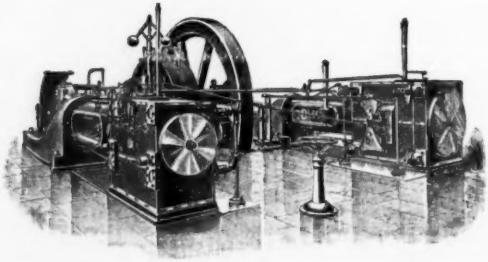

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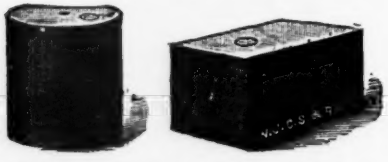

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Experiments with an air motor on the Elevated Railroad, New York, are certainly novel and interesting. What has been done thus far by the American Air Power Company with the Hardie motor has marked a step much in advance of past practice, and further developments in this line will be watched with interest by engineers.

Attention is called to a valuable paper published in this number, entitled "Compressed Air: Its Production, Transmission and Use." Mr. Wm. Prellwitz, the author, is an engineer of experience and well known ability in this line; our only regret being that he does not more frequently give the public the benefit of his knowledge of compressed air and air compressing machinery. His paper is an excellent combination of theory and practice, and the subject is so clearly stated that it cannot fail to be of interest both to engineers and laymen.

"Liquid Air and Its Uses," by Mr. G. D. Hiscox, in the August number of COMPRESSED AIR, was an interesting compilation of recent articles on this subject. Some of the matter was taken from an article by J. E. Seibel in "Ice and Refrigeration," May, 1897; also from a very valuable paper on the subject written by Mr. E. A. Rix and published in the "Electrical Engineer." He was also aided by a letter of Chas. DeKay, Consul General, Berlin, Germany, who made a report on this subject.

We published in the August number of COMPRESSED AIR a description, with illustrations, of the first machine used for the production of artificial ice. This machine was invented by Dr. John Gorrie, of Apalachicola, Fla., and its interest and importance are based upon the fact that the fundamental principles involved by which low temperatures were reached are practically identical with present theory and practice. Dr. Gorrie used compressed air to produce cold, and though the important industry of refrigeration is now mainly based upon the use of ammonia, yet the principles involved are the same. Dr. Gorrie in his specifications said:

"It is a well known law of nature that the condensation of air by compression is accomplished by the development of heat, while the absorption of heat from surrounding bodies, or the manifestation of the sensible effect commonly called cold, uniformly attends the expansion of air; and this is particularly marked when it is liberated from compression. The nature of my invention consists in taking advantage of this law to convert water into ice artificially by absorbing its heat of liquefaction with expanding air."

We neglected to mention the fact that the illustrations and interesting description given of this apparatus were furnished by Mr. GEORGE H. WHITESIDE, of Apalachicola, Fla., who erected the Apalachicola ice factory, and who is now the general manager of the Apalachicola Ice Co.

The substance of Mr. Whiteside's paper was given in a more extended article by him which was published in "Ice and Refrigeration," in May, 1897.

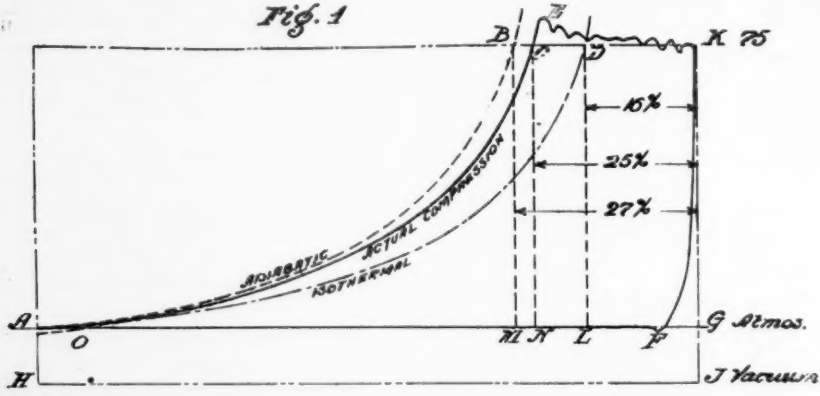
Compressed Air: Its Production, Transmission and Use.

An Address delivered at Lafayette College, Easton, Pa., by Mr. William Prellwitz.

Air being such a common subject, requires no introduction. Compressed air is simply air under pressure, or air increased in density by pressure or by heat. It is one of the oldest of the sciences, although in its general application one of the youngest, for it is only within the last thirty or forty years that compressed air has been used for mining and tunnelling, for which no other power was available, and in fact in all the early uses of compressed air it was only used where it was considered a necessity regardless of expense, it having always been termed an expensive power. It is true that it takes work to compress air, although the writer has heard of instances where contractors, when the compressor first became known, wanted to run drills on open rock work with compressed air, thinking they would thereby abandon their boiler plant and save buying coal, their idea of a compressor being a machine which would furnish air without using power, or, in other words, a modified form of perpetual motion. It is also true that there are losses in the compression and use of air to which no attention was paid in the earlier machines, and which exist in many plants to-day, where, however, the great convenience of the air and its saving in many other ways, more than make up for the loss due to the compressor.

The one great loss in the compression of air is due to the heat caused by compression and the consequent increase in the volume of the air. The minor losses are clearance in the air cylinder, the heating of the intake air in passing through the valves, and the friction of the compressor. The first two of these amount to very little, and are hardly noticeable in a good machine. The last loss mentioned, friction, amounts to from 7 to 15 per cent., depending to a great extent on the amount of care that is taken with the machine. To clearly illustrate the work that is done in an air cylinder, we have recourse to the indicator, and the following diagram, Fig. 1, shows an indicator card taken from a water jacketed air cylinder (the card having the isothermal and adiabatic lines plotted on same), an examination of which

Fig. 1



gives us the actual results obtained.

Referring to Fig. 1, we have the adiabatic or heat line A–B, which represents the work done if there were no cooling effect in the cylinder, the line A–C representing the actual work done in the cylinder, and the isothermal or constant temperature line A-D, which is the line the indicator would make if all the heat generated could be carried off during the work of compression.

This latter condition does not exist in our high speed machines of to-day, but one can imagine it to exist in a machine where the piston travels slow enough that all the heat would be carried off by the water jacket or by radiation. In following the movement of the piston in the cylinder, suppose it start at A, the cylinder

then being full of free air, and moves to the right, the pressure in the cylinder at any point is represented on line A-C. When the piston reaches C, it has compressed the air to the receiver pressure and it must then push the compressed air out through the discharge valves into the receiver. Owing to the weight of the discharge valves and the tension of the springs holding them to their seats, the pressure in the cylinder reaches a few pounds above the receiver pressure before the valves open, as shown at E, and there gradually drops to the receiver pressure at the end of stroke, the irregularities in the line being due to the fluttering of the discharge valves and the vibration of the indicator arm.

The piston having reached the end of stroke, comes to a standstill while the crank is passing the dead center: and as the current of air that held the discharge valves open in passing out of the cylinder has ceased, the discharge valves close by the tension of the springs back of them. The piston now starts to recede,—the air under pressure that was left in the cylinder due to the clearance space expanding until it becomes atmospheric pressure at F, when the inlet valves open and the cylinder is filled with free air. If the indicator line follows along the atmospheric line, we know that the inlet area is not restricted and we are getting a volume of free air at atmospheric pressure represented by the travel of piston from F to A, this representing the actual free air capacity of the machine. The volume between G and F representing the air contained in the clearance space, expanded, is lost as far as the capacity of the machine is considered; and although this air required work in compressing it to 75 lbs. pressure, it has given out its work in expanding, helping to compress the air on the other side of the piston.

The only loss in work due to the clearance space is that resulting from the small amount of cooling that the confined air has been subjected to, its volume when hot having been a trifle more and having required more work to compress it, but this is rarely taken into account. We thus see that the clearance space in the cylinder is not a loss of power, but a loss of capacity, which is allowed for by deducting anywhere from 3 to 10 per cent. of the cylinder volume, according to the design of the air cylinder and the length of stroke of same,—it being evident that the longer the stroke for the same size cylinder the less will be the percentage of clearance. On some indicator cards it is noticed that the intake air pressure falls below the atmospheric line, showing that the air inlet is restricted, or, as is common on air cylinders having poppet inlet valves closed by a spring, the tension of the spring when the piston is moving slow at the end of the stroke, will close the valves before the piston has completed its stroke, so that when the end of stroke is reached a partial vacuum is formed in the cylinder. Where these defects exist, the piston must travel a distance as A-O before the atmospheric line is reached, and the volume of the cylinder would be O-F, instead of A-F, making the 10 per cent. allowance for clearance necessary, while 3 to 4 per cent. should be sufficient on a well designed machine.

The temperature of the air at 75 lbs. gauge pressure without any cooling is 419 degrees, although this is somewhat lower in the cylinder, due to the jacket cooling; and from actual readings on thermometers placed in the discharge pipe close to the cylinder, the temperature is from 300 to 360 degrees, according to the size and speed of the machine.

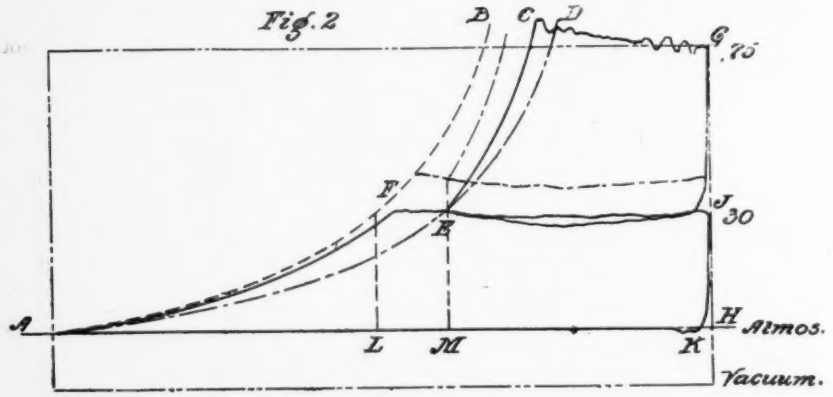
Referring again to Fig. 1, we have the volume C-K-N-G, representing about 25 per cent. of the free air volume at, say, 340 degrees temperature, to put into the receiver at each stroke of the machine. As the receiver is anywhere from 10 to 20 ft. from the compressor, and as it has a large surface exposed for radiation, its temperature will be considerably less than that of the air leaving the cylinder, which will consequently be cooled and reduced in volume; and as the air is generally used a considerable distance from the compressor, it will have reached atmospheric temperature by the time it is used and our original volume C-K-N-G, when leaving the cylinder, will have shrunk to D-K-L G by the time it was used, being then only 16-25 of what we would have had had the air been used hot directly as it left the compressor.

This shows us clearly the two most important factors where a large saving can be effected in the production and the use of air,—the first being to cool the air as much as possible during compression, and the second to heat the air as much as possible before using; and although the above diagram represents the actual conditions of many of the small compressor plants in existence in which the air is used as ex-

plained, these losses can be and are successfully overcome in most of our large compressor plants of to-day where air is being produced and used, with a less expenditure of coal than if steam were used direct, leaving all the saving by the use of the air as a clear gain for the operators.

Turning our attention now to the main factor for the economical compression of air, which is to cool it as much as possible during compression, we having the following styles of compressors for the accomplishment of same, namely: the wet compressors or those in which water is used in the cylinders; the dry or water-jacketed compressors, and the compound or stage compressor, where the work of compression is done in two or more cylinders, the air being cooled in passing from one to the other.

Fig. 2



Of the first named style there are two forms, one being that in which the water is let into the cylinder with the incoming air, and the other in which the water is injected into the cylinder in the form of a spray while the air is being compressed. In the first form there is a great deal of water in the cylinder, which then very much resembles a pump, but as the air and water do not become mixed, the air is but very little cooled, while the water, on the other hand, reduces the efficiency of the machine by the increased friction in the cylinder and the slower speed that the compressor must be run at. The water injection machine, on the other hand, is the best known way of cooling the air in a single cylinder, but as it still retains all the disadvantages of having water in the cylinder, causing often the rapid wearing of the parts, all of the American compressors of to-day are made with water jacketed cylinders, the loss in economy being more than counterbalanced by having a machine which will not require the constant renewal of parts.

In designing an air cylinder, the object is to get as much of the body of the cylinder and heads jacketed as possible, the heads in particular being the most effective, as they are exposed to the air during the entire length of stroke, while the body surface diminishes as the piston travels toward the head. The smaller the air cylinder the more effective is the jacket, for in cylinders of different diameters the volume of air they contain is proportional to the square of their diameter, while the cooling surface is in the direct ratio of the diameter; that is, if one cylinder were twice the diameter of the other, it would hold four times the volume of air and only have about twice the cooling surface, being thus only one-half as efficient as the small cylinder. Compressors have been built where the air cylinder proper was made up of a great number of small cylinders all enclosed in water, and they have given very economical results, but they are expensive to build and very liable to get out of order owing to the large number of small valves required for the many cylinders.

The most economical way of compressing air is by doing it in stages; that is, using two or more cylinders, compressing it to a low pressure in the first, then passing it through a cooler cooling it to atmospheric temperature and then further

compressing it to a higher pressure, cooling it and compressing it again, and so on, depending on the pressure required, the two-stage or compound compressor being used for pressures between 60 and 300 lbs., the three-stage or triple compression between 300 and 1000 lbs., and the four-stage or six-stage between 1000 and 3000 lbs., or higher.

We have in Fig. 2 a combined indicator card of a compound compressor, in which A-B is the adiabatic, A-D the isothermal, and A-F-E-C the line showing the actual work done in the cylinder. The low pressure card is represented by A-F-J-K, the pressure reached in same being governed by the size of the high pressure cylinder and the efficiency of the intercooler. The distance, H-M, represents the volume of the high pressure cylinder in proportion to the low pressure cylinder represented by H-A, the diagram showing that the compression line in the high pressure cylinder starts at the isothermal line, showing that the air was cooled to atmospheric temperature before entering the high pressure cylinder.

The compressed air leaving the low pressure cylinder is represented by F-J-H-L, and passing through the cooler it shrunk in volume to E-J-H-M, representing the size of the high pressure cylinder. Had the cooler not been perfect, the air would have retained part of its heat, keeping its volume consequently larger, and a higher pressure would have been necessary in the low pressure cylinder, the card then being as shown by the dash-dotted line representing more work done in the cylinder. This shows the necessity of having a perfect cooler, the important part of which is that the air is broken into thin sheets so that it can be easily cooled. The air and water should also travel in opposite directions, so that the air in leaving the cooler meets the coldest water, and the cooler should also hold a sufficient volume of air so that there will be no drop in the intake air pressure of the high pressure cylinder.

Comparing the compound cylinder card, Fig. 2, with Fig. 1, it is seen that the amount of work represented by F-B-C-E has been saved, amounting to about 14 per cent. of the total work, or where it took 16 H. P. to compress 100 cu. ft. of free air to 75 lbs. in a single cylinder, a compound cylinder would use 13¾. Where air is to be compressed to higher pressures, the saving in compounding becomes more marked,—500 lbs. pressure requiring 40 H. P. for compressing 100 cu. ft. of free air in a single cylinder, and 30 H. P. in a compound cylinder, or a saving of 25 per cent., this percentage increasing with higher pressures, and at 2000 lbs. using four cylinders for doing the work, the work saved over a single cylinder is 45 per cent.

As the object is to cool the air as much as possible during compression, the colder the air is to start with the better; thus a considerable saving can be effected by taking the air supply from as cold a place as possible, carrying the air through a wooden box to the compressor. Approximately for every 5 degrees that the intake air is colder than the air in the engine room, a saving of one per cent. is effected in the running of the machine; and as there are many days in the winter months where there is a difference of 50 degrees between the temperature indoors and outside, a saving of 10 per cent. can be effected by supplying the compressor with the cold air from outdoors, instead of using the hot air of the engine room. Using cold air increases the capacity of the machine, a difference of 50 degrees in the air used amounting to about 10 per cent. increase in the amount of air the compressor will deliver.

We have so far in our figures been dealing with compressed air at sea level where the atmosphere has a pressure of 14 7-10 lbs. At higher altitudes the atmosphere is more rarefied, representing less pressure per square inch, as shown by the following table :

PRESSURE.

At	¼	mile	above	sea	level—	14 2	lbs. per	sq. inch.
"	½	"	"	"	"	—13.33	" "	"
"	¾	"	"	"	"	—12.66	" "	"
"	1	"	"	"	"	—12.02	" "	"
"	1¼	"	"	"	"	—11.42	" "	"
"	1½	"	"	"	"	—10.88	" "	"
"	2	"	"	"	"	— 9.88	" "	"

Or an approximate reduction of ½ lb. per square inch for every 1000 feet of ascent. Owing to the rarefied condition of the air at high altitudes, it is evident that when this air is compressed its volume under pressure will be considerably less than if the same volume of free air at sea level pressure had been compressed to the same pressure

According to Mariotte's law, the pressure of any gas varies in the inverse ratio of the volume, the temperature remaining constant, or the volume of a given quantity of gas is inversely as the pressure it supports; or representing

P' as being the absolute pressure at any point of the stroke,
P the original absolute pressure,
V the volume corresponding to the required point of the stroke,
we have for the pressure at any point of the stroke,

$$P' = \frac{P}{V}$$

or for the volume at any point of stroke—

$$V = \frac{P}{P'}$$

Remembering that in all computations absolute pressures (pressures above vacuum) are to be taken, and not gauge pressures; remembering also that the results obtained will be in absolute pressures from which the atmospheric pressure must be deducted to obtain the gauge pressure. Applying Mariotte's law in determining the difference in volume by compressing at sea level or at an altitude, suppose we compress one cubic foot of free air at the sea level to 75 lbs. gauge pressure, which equals 90 lbs. absolute pressure, we have by Mariotte's law—

$$V = \frac{P}{P'}, \text{ or } V = \frac{15}{90}$$

Suppose we were compressing air at an altitude of one mile, where the pressure of the atmosphere, according to our table, is 12 lbs., we have by the same law—

$$V = \frac{P}{P'}, \text{ or } V = \frac{12}{87}$$

or only about 4-5 as much air as when at sea level.

As many air compressors are now used at high altitudes, allowance is made for this loss by deducting a certain percentage; in the above case, 20 per cent. from the rated capacity of the machine, amounting to 7 per cent. at ¼ mile altitude, and increasing about 4 per cent. for each additional ¼ mile of altitude, at two miles the loss being about 34 per cent.

As the volume of air decreases, the required power of the compressor also decreases, but the capacity decreases in a greater ratio than the power necessary to compress, hence it follows that operations at a high altitude are more expensive than at sea level. At 10,000 ft this extra expense amounts to over 20 per cent.

Having now given a general description of the work done in an air cylinder, I will briefly describe the construction of the air compressors that are in general use to-day. Probably the simplest and the best machine for a small plant is what is known as a straight line self-contained machine, in which the air and steam cylinders both in a direct line are fastened to a common bedplate.

Fig. 3

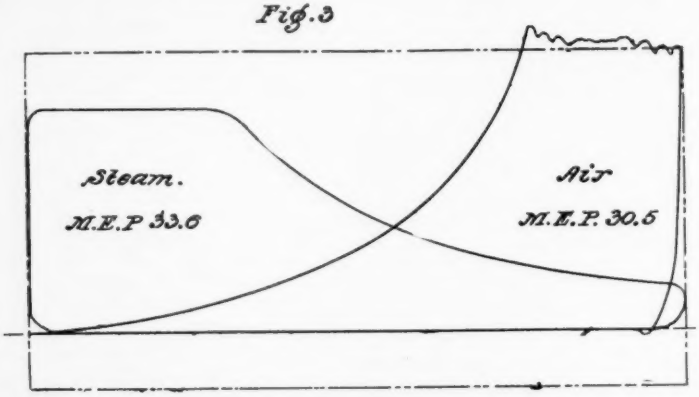


Fig. 3 shows a steam and air indicator card taken from such a machine, from which it is seen that the greater part of the work in the steam cylinder is done at the beginning of the stroke, while in the air cylinder it is done at the latter part of the stroke. To make this possible where steam is to be used expansively, as shown in the card, it is necessary to use heavy flywheels and reciprocating parts on the machine, the energy of the steam cylinder at

the beginning of the stroke being stored in the fly-wheels, which in turn give up their energy in compressing the air at the end of the stroke.

The question is often asked, How is it possible with the same size cylinders to get a higher air pressure than the steam pressure used? By referring to Fig. 3, it will be seen that the steam card represents a higher mean effective pressure than the air card, showing that the steam cylinder has done the most work owing to the friction of the machine, although the air card shows the higher pressure. This is due to the energy of the steam cylinder being stored in the fly wheels, and where the fly wheels are made sufficiently large and heavy, no trouble is experienced in getting from 50 to 75 per cent. higher air pressure than the steam pressure used; this, however, being very poor steam economy, as it would be necessary to cut off late in the steam cylinder, utilizing very little of the expansive power of the steam. For good economy, working at about 80 lbs. steam and air pressure, the cylinders should be about the same diameter, thus allowing from ¼ to ⅜ cut-off in the steam cylinder; or if higher air pressures are required, the size of the steam cylinder should be increased accordingly.

It must not be understood that a compressor cannot be built without a fly wheel, for there are thousands of such in everyday use, by which I refer to the air pump used on every locomotive. It would not be fair to criticize this machine in connection with the duty it performs, for it has too well stood the test of years, its lightness and compactness being more valuable features than economy in the use of steam; but commenting on the same, when used in a shop we have but to understand that for each stroke of the machine a full cylinder of steam is required at the maximum air pressure, comparing which with the fly wheel compressor where steam is cut off at ¼ stroke, shows that the air pump has used four times as much steam as the air compressor would have used for compressing the same amount of air.

Another form of wheelless machine is that in which the air cylinder at each stroke and after being filled with free air, is filled with air at receiver pressure by opening the discharge valve at the beginning of stroke. The air cylinder now has a uniform maximum load for its entire stroke resembling the water cylinder of a pump, but this also necessitates a whole cylinder of steam at maximum pressure to do the work.

Attempts have been made on wheelless machines to use steam expansively by making the reciprocating parts, noticeably the crosshead, of sufficient weight that their momentum would compress the air at the end of the stroke after the steam had been cut off, but a machine of this kind can only be designed for a fixed speed and pressure, the weight being too heavy if run faster, and not of sufficient weight to do the work if run slower,—making in all a poor substitute for a machine that is called upon to do a variable amount of work. From these accounts it is seen that the fly wheel is really a necessary part for an economical compressor.

The straight line compressor is made with many different arrangements of cylinders, the steam cylinders, air cylinders or both being compounded, but in all of these the work of the cylinders is in a direct line and the fly wheel uses its stored up energy twice in each revolution to overcome the maximum load at the end of stroke.

To more uniformly distribute the work during each revolution, the duplex form of compressor has been adopted as the best type for the larger and better machines. This is essentially two straight line machines placed side by side with a common shaft for the two, the cranks of same being set at 90 per cent. to each other. This divides the work through four parts of the revolution, making the machine more uniform in its motion and allowing it to run slower and with better steam economy than a straight line machine, avoiding also all dead centers, so that the machine can be started up at any part of the stroke. The duplex compressor is also made with different arrangements of cylinders. the best types being those having cross compound steam and air cylinders.

These two types of machines are to-day considered the standard; but as an air compressor is but a steam engine with an air cylinder attached, it has probably been built in every form, whether horizontal or vertical, that a steam engine has ever been built.

In determining the style of compressor best suited for the given duty, conditions such as the size of plant, cost of fuel, the length of time the plant will be used, cost of foundations and first cost of machine must be considered, for the higher the efficiency of a compressor the greater will be its first cost; but for a permanent plant no

machine can be too good or too economical in its operation.

As air is generally used under the same conditions and with the same machinery that uses steam, the true way of comparing the efficiency of a compressor would be to compare the volume of cold compressed air that the compressor will furnish with the volume of steam the compressor used at the same pressure to furnish the amount of air.

Assuming it thus, the efficiency of a straight line compressor, non-componnd, would be about 60 per cent.: a duplex Corliss compressor, non-compound, about 65 per cent., and a duplex Corliss compressor with compound condensing steam and compound air cylinders with intercooler, about 90 per cent., or in the latter case we would have 90 per cent. as much cold air as steam that was used. If we consider for a moment the properties of compressed air as compared to steam, we find everything in favor of the air, as it remains ever ready to be used, regardless of the exposed condition of the pipes through which it passes, while steam, if carried around in uncovered pipes outdoors, condenses very fast, this condensation often amounting to from 15 to 30 per cent., so that if air was used under these conditions it would be more economical than steam, without taking into consideration the great convenience of the air and the saving it effects in the increased running of the machinery, less friction, saving of hose and oil, and the ease with which all machinery and pipes can be handled owing to their being always cool. We have thus far only considered the use of air when in a cold condition, but far greater economy can be obtained by heating the air before using, as will be explained later on.

We often read lengthy articles on the efficiency of an air compressor plant where the compressor and all the pumps and hoisting engines or machinery that used the air were carefully indicated and figured out, and they find that the work the air done in horse-power is only about one-third of the indicated horse-power of the compressor; or in other words, that the compressor plant has only an efficiency of 33 per cent. This certainly looks very unfavorable for the use of compressed air, but it nevertheless is a condition which exists, the reason for the same being due to the very uneconomical machinery with which air is always used, and it is this uneconomical use of air which has done much to keep it from being more generally employed as a power.

The above statement as to the efficiency of a plant is, however, misleading, unless one takes into consideration as to how the power is measured at the compressor and how the air is measured in being used. The indicated horse-power of the compressor is the amount of work done in compressing the air, using, however, in an economical machine the full expansive power of the steam, or at the end of the stroke when the steam cylinder is ready to exhaust, no pressure, and consequently no work, is left in same.

In the pumps, hoisting engines or drills using the air, we have, however, a different condition. Here the cylinders are filled full of air under pressure, and at the end of stroke, when the cylinders open to exhaust, the whole cylinder-full of air under pressure is allowed to escape into the atmosphere, utilizing none of the expansive power contained in same; in other words, the power is supplied or measured at the compressor when used in the most economical way, while the air is used in the most wasteful way, hence accounting for the poor showing; but it must be remembered that the machine which used the air would use steam under the same wasteful conditions, and would show a correspondingly poor efficiency if compared with the same volume of steam used expansively in an economical engine. The amount of steam used to compress the air, if used direct in the pumps and hoists, would be but little more than enough to run the same, and the efficiency of the compressor plant would be from 60 to 90 per cent., according to the compressor, when compared with the volume of steam used, as against 33 per cent. when horse-powers are figured. Hence, as previously stated, the only intelligent way of making comparisons of the efficiency of the air system would be to compare volumes, and not horse-powers.

TRANSMISSION OF AIR.

Of the transmission of air very little need be said, for it is simply carried around in pipes, the same as steam or water, but being more easily handled than either, for no matter what the length of pipe, there will be no condensation as with steam, and no shock as with water. As to the distance that air can be carried, that depends entirely on the volume of air and the size of pipe, the only loss being

a reduced pressure at the end of pipe line, caused by friction if the pipe is not of sufficient size, but at this reduced pressure the air has a larger volume, so that the loss is not as much as the fall in pressure would make it appear.

Air pipe lines have in different places been laid for distances of 15 miles or more, but the average pipe lines in tunnels and around quarries run from 1000 to 10,000 feet, for which conditions the pipes can generally be made large enough at a small expense, so that the friction will only amount to a few pounds loss of pressure.

As a practical example of what would be required, if 1000 cu. ft. of free air compressed per minute to 80 lbs. pressure, was to be carried a distance of 5000 feet, a 5-inch pipe line would show a loss of pressure of about 6 lbs., and a 6-inch pipe about 2½ lbs., all elbows in the pipe line increasing the friction. so as few as possible should be used. The friction loss may be considered for ordinary purposes as being proportional to the length of pipe and as the square of the velocity of the air, twice the volume passing through the same size pipe giving about four times the friction.

A receiver should always be placed close to the compressor, to better equalize the work on same, answering also at the same time as a separator, taking much of the water and oil out of the air, these dropping to the bottom of the receiver, where they are blown out at frequent intervals. A second receiver should be placed where the air is to be used, as the air being still further cooled will drop most of its moisture, which can be again blown out at the second receiver, leaving dry air to be used in the machine. All pockets in pipe lines should be avoided, as they have a tendency to hold water and thus retard the free passage of the air; and wherever a machine is used at the end of a long air pipe draining in the direction of same, provision should be made for blowing out the water before using the air. Should it become necessary to pass air through a pipe line, which must of necessity have many pockets in same, so much water may be held in the pockets that very little air pressure would be gotten at the end of the line. Where these conditions exist, much trouble can be avoided by thoroughly cooling the air (thereby taking out all its moisture to a temperature lower than that of the pipe through which it will pass, so that the air will have a tendency to take up moisture in the pipe instead of dropping its water in same. By doing this the air pipe will always remain free, so that the full air pressure will be gotten at the end of the line. For carrying the air to cranes and hoists rubber hose has admirably fulfilled the requirements, for with the use of quick-acting couplings or a line of hose wound on a drum, every convenience has been obtained.

USE OF AIR.

In the use of air, about the only objection that has been offered to the same is the freezing up of the exhaust. Whenever air is used expansively, it must draw its heat from the surrounding objects, and if any moisture remains in the air it will have a tendency to freeze the same. The freezing of the exhaust can be avoided by having the air perfectly dry before using, hence the object of the receivers and drains; or if this is not possible, a small stream of water about the size of a needle in the exhaust will have the desired effect. As these preventives to frost, however, do not add any to the economy of the system, the only true way of overcoming all the tendency of the air to freeze is to reheat the same before using, getting back all of the work or the volume of the air that was lost in cooling while passing from the compressor to where it was to be used. This heating of the air is to-day successfully and economically accomplished, the heating of same increasing its volume from 35 to 50 per cent., this increase costing only about one-sixth the amount of coal in the heater that the compressor used for compressing an equal volume of air.

Heaters in use to-day are made similar to a stove where the air in thin sheets passes over the heated sides of a jacket, or other forms are made where the air passes through hot water, both of these having been very successful in their application.

When a compound condensing compressor, with compound air cylinders producing about 90 per cent. as much cold air as steam that was used, has the air reheated before it is used, we can easily see how the compressed air plant can claim to have an efficiency of about 20 per cent. more than if steam were used direct, regardless of the many other advantages and conveniences that are due to the air.

The Air Motor.

A TRIAL TRIP ON THE ELEVATED RAILROAD, NEW YORK.

The Hardie Air Motor, which was built by the American Air Power Co. to demonstrate the possibility of using it to draw trains on the Manhattan Elevated Railroad, New York City, was put into service on Thursday evening, Aug. 19, and a public test of it was made by taking a train loaded with 192 persons over the Sixth Avenue road from Rector street to Fifty-eighth street and back to Cortlandt street.

The motor, with five cars attached, started a little after nine o'clock. Robert Hardie, the inventor, was in charge of the engine, having a regular engineer as pilot.

The train followed a regular train and made the run in 19 minutes, this being 3 minutes faster than the scheduled time. The time on the return trip, making all stops, was 26 minutes.

Among the passengers were a large number of representative railroad men and men interested in compressed air matters. Everyone admitted that the trial was most successful and all that could be desired.

The Hardie Compressed Air Locomotive in its main features of construction is substantially identical with that of the steam locomotives in use by the Manhattan Railway. Its length is the same, its driving wheels the same, but its maximum weight when manned and ready for service is less than that of the steam locomotive. The wheel base of the driving wheels being six feet instead of five feet as on the steam locomotive, makes it permissable to place a greater weight on the drivers than is allowable on the steam locomotives, without increasing the strain on the structure, thus giving it increased tractive power and enabling it to take the sharp curves on the line easier. The cylinders are 13 inches in diameter by 20 inches stroke, and the valves are specially designed. The variable cut-off is controlled by a hand wheel in place of the notched quadrant used on the steam locomotives. Two independent ways are provided for applying the air brakes, and in addition the locomotive has a compressed air-driving wheel-brake of novel design, thus affording additional security against accident. In place of the boiler and firebox of the steam locomotive, there is a bundle or nest of seamless steel flasks, 9 inches in diameter and about 15 feet long, having a total capacity of about 150 cu. ft., in which the air compressed to 2400 lbs. pressure per sq. inch, is stored. In operation, the compressed air passes from these flasks through a regulating valve and is delivered at a uniform pressure into a low pressure receiver, where the air is re-heated by passing through hot water and is then applied to the cylinders at a uniform working pressure of 150 lbs. per square inch. The method of storing the air reducing the pressure, re-heating and controlling, as well as the application to the cylinder, is the result of many years of study and experimental work by Mr. Hardie, whose efforts have been unequalled.

The air to charge this locomotive is compressed at 100 Greenwich street by an Ingersoll-Sergeant four-stage compressor, and conveyed by pipe line through Greenwich street to Rector street, and thence up Rector street to the Sixth Avenue Elevated structure, to the point where the steam locomotives take their water. It does not take any more time to charge this locomotive with air sufficient for a run to Fifty-eighth street and back, than it does to take water on an ordinary steam locomotive. The Mannesmann tubes furnished by Chas. G. Eckstein & Co., 45 Vesey street, New York, are in use both on the motor and in the power house.

Mr. Chas. G. Eckstein, of the firm of Chas. G. Eckstein & Co., New York, who has for some time past made a study of the development of the use of pneumatic tools in this country, has just opened a branch office at 58 Spandauer Strasse, Berlin C., Germany, for the introduction and sale of pneumatic tools and specialties in this line.

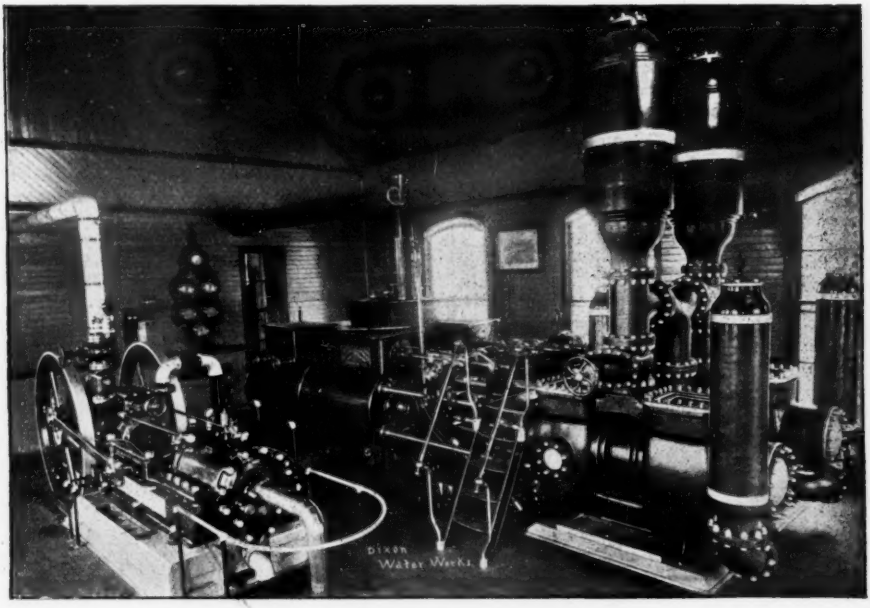
Water Works at Dixon, Ill.

The water supply at Dixon, Ill., is derived from three artesian wells, seven inches in diameter, and from 1630 to 1800 ft. deep. Two of the wells flow into a reservoir of 500,000 gallons capacity. When the reservoir is empty, these two wells flow at the rate of 566 gallons per minute, but when it is full and the well tubing submerged, the flow drops to 123 gallons per minute.

While this amount of water, together with the flow of the third well, is sufficient for ordinary requirements, it was not adequate during the summer months, and to increase the supply at a minimum expense, it was decided to install the air lift system.

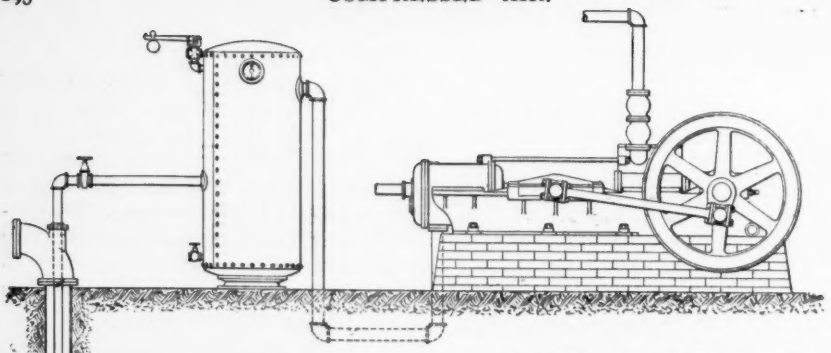
The air compressing plant was furnished by the Ingersoll-Sergeant Drill Co., of New York, and included a Class "A" Piston Inlet Air Compressor, having 14" diameter steam cylinder, 16¼" diameter air cylinder with 18" stroke.

At a recent test of the two wells flowing into the reservoir, they were able to secure 1261 gallons of water per minute by the air lift, with the reservoir empty, and 1212 gallons per minute with the reservoir full and the well tubing submerged. This increase is equivalent to almost ten times the flow of the wells under the latter conditions. The compressor is operated at only 56 revolutions per minute.



PUMPING PLANT AT DIXON, ILL.

The accompanying illustration shows the engine room at the water works station. The large Gordon & Maxwell pumping engine shown in the illustration has a capacity of 2,500,000 gallons in 24 hours, while the small compressor to the left, running at only 56 revolutions per minute, is pumping nearly four-fifths of this amount from only two wells. If connected to all three wells, the compressor would readily deliver into the reservoir all the water the large pumping engine could possibly handle.



Pumping Water by Air.

While much has been said of the Air Lift and its advantages over other systems of pumping water, it is not always clearly understood what such an outfit consists of, and we therefore give the following illustration.

As will be seen, the outfit includes an air compressor, which may be either steam-actuated or belt-driven; an air receiver to equalize the flow of air to the well, and the piping in the well.

The compressor is located in the engine room, where it is always under the eyes of the engineer; and as compressed air can be conveyed for miles without loss, the well may be any distance away.

The air receiver may be placed either inside or outside of the engine room, whichever is preferable. If located outside, the pressure gauge can be attached to one of the walls of the engine room.

The method of piping a well differs, we are told, according to its general conditions and the quantity of water to be pumped. No two wells are alike, and consequently the method of piping which might be applied to one would be unsuited to another. This, however, is not very generally understood.

In the accompanying illustration the method of piping consists of using the well casing as the water discharge pipe and simply putting a small air pipe down in the well, with a special device attached at the bottom through which the air escapes. Another method consists of placing the air and water pipes alongside of one another in the well, connectiug them at the bottom with an end piece. A third method places the water discharge pipe into the well, the air passing down through the annular space between the well casing and the water pipe. While each is different from the other, yet the principle as patented by the late Dr. J. G. Pohle is the same—i. e., the water is raised by compressed air.

The advantages of the air lift system appear numerous. At the Fort Madison, Ia., Water Works, it pumps 3,000,000 gallons of water a day from a well 12" in diameter and only 100 ft. deep. At the Charleston, S. C., Water Works about 300 tons of quicksand was raised with the water. This would not have been possible with any other pump. At the Ocean Grove, N. J., Water Works twenty wells are operated by one compressor; the wells are widely scattered, and some of them are almost half a mile away from the engine room. At the Asbury Park, N. J., Water Works it helps to purify the water by precipitating the iron with which it is strongly impregnated.

COMMUNICATIONS.

Under this heading will be published inquiries addressed to the Editor of COMPRESSED AIR. We wish to encourage our readers in the practice of making inquiries and expressing opinions.

We request that the rules governing such correspondence will be observed, viz: all communications should be written on one side of the paper only: they should be short and to the point.

Overloading Compressors.

Editor "Compressed Air."

There is a source of heat, produced in the air cylinders of a compressor, due to overloading, which is often attributable to the over-work put on the air receptive devices.

The internal effects of excessive demands for air upon a compressor are somewhat similar to those made on an electric generator, or the overloading of an electric motor—i. e., to produce undue heat; and, for efficiency and safety, a compressor and driven devices should be operated as skillfully as electrical machinery.

While the additional volume of air required does not increase the pressure, nor the temperature due to pressure, yet it increases the friction through valves and on cylinder walls. This, augmented by lack of working freedom of valves, may assume serious proportions.

It is a noticeable fact that not a few stationary engineers are somewhat indifferent as to the amount of work they expect from a compressor, though at times overloading is momentarily beyond their control.

HERTFORD C. CHAMP.

New York.

Editor "Compressed Air":

DEAR SIR—I am very much interested in the discussion now going on in your very instructive little magazine, COMPRESSED AIR, on the subject of explosions and fires in air compressing engines and air receivers. As I have had considerable experience in the handling of compressors, I give you my idea as to the cause of some of the explosions that occur in this type of machinery.

Some ten years ago, during the construction of the New York Croton Aqueduct, I had charge of the machinery at Shaft No. 16, Section 8. We had a duplex air compressor at work with air cylinder 18" diameter x 30" stroke, and maintained a working air pressure of from 80 to 90 lbs. per square inch. The compressor was of the ordinary poppet valve type, and we had the usual trouble with this type of valve—that is, one or more of the valves would stick, due to the carbon deposited on them. The oil used was the best obtainable for this purpose, and was recommended by the manufacturers of the compressors. The air receiver (horizontal) was situated outside of the engine house and was exposed to the hot rays of the sun. On one occasion, in passing the receiver, I noticed that the rubber gasket between the flanges of the air discharge pipe and receiver was on fire, and the pipe itself was red hot. I stopped the compressor soon as possible and took the manhole plate off receiver and found the inside on fire. We got out the fire hose and soon had the fire under control. After the receiver cooled off we made an examination to find out, if possible, what was the cause of the fire, and found the entire interior of the receiver encrusted with carbon at least ⅛" thick. In the meantime, while we were fighting the fire, several miners who had been running rock drills in the tunnel were knocked out by the fumes of the burning carbon and brought to the surface in an insensible condition. This being our first experience of this kind, we were at first at a loss to account for the fire. We started to investigate, and were not long in discovering the cause. As stated in the foregoing, the air cylinders were provided with the ordinary poppet valves, and frequently several of them would stick, and when the engineer would notice that they did not work, would take a squirt-can filled with kerosene oil and squirt a quantity of the oil at the valves to cut the sticky substance; the oil was immediately drawn into the cylinder, and being of a very low flash test, would quickly vaporize, and when the conditions were just right would ignite and cause an explosion or fire. I have since noticed that this habit of using kerosene oil as above stated is quite a common practice with engineers who run poppet valve compressors. I have no doubt that this is the cause of many of the fires and explosions that take place in compressed air engines.

Yours truly,

PHILIP WEISS.

NEW YORK, Aug. 19, 1897.

Editor "Compressed Air"

DEAR SIR: We have before us your issue of July, 1897, and in it we note remarks in reference to ignition in air cylinders of air compressors. This to us is a very inter-

esting subject, and, as you know, we have devoted a great deal of time and money to it, and we are glad to place before you some few facts which may interest your correspondents.

That the occasional occurrence of fire in air compressors is due to the oil present, there can be no doubt, as the oil is the only substance present which can burn; and in this connection we beg to say that the cause of this difficulty cannot be laid to the oil alone, although it is a well known fact that an inferior oil which contains a large amount of carbon and other foreign substances can readily cause explosions.

That certain structural features of a given machine may facilitate or retard combustion of the oil, will, we think, appear from what follows:

The fact of an air compressor drawing the air from whatever location the compressor may be in, naturally necessitates the presence in the air cylinder of whatever foreign substance there may be in the atmosphere. For instance, in acid or alkali works, coal mines, copper mines, or other places of a similar character where there is an unusual amount of dust or foreign substance in the atmosphere, which being drawn into the air passages of the machine, combines with the excessive amount of residuum or carbon left behind through oxydation, forming a substance for fire to feed on, the fire resulting from causes herein set forth.

Our experience is, that the greatest amount of oxydation takes place at the point where the air passes from the cylinder into the discharge pipe. The result is that continued oxydation naturally decreases the size of the aperture at the mouth of the discharge pipe, and more air is compressed in the cylinder than can pass through the discharge pipe—the result being the re-compressing of the air, and an increased amount of friction, also an abnormal degree of heat in the air cylinder. The result from such cause is very apparent.

As to the oil, it should have the least liability to oxydize that it is possible to secure. The flash point should be as high as good lubricating qualities will permit. What is the flash point? It is that degree of heat at which some constituent part of the oil passes off as vapor, which vapor being inflammable, will ignite if brought in contact with fire.

The mere raising of the temperature of an oil to its flash point will not produce ignition Another cause must be presented to produce ignition of the vapors. Indeed, such a cause may operate before the flash point is reached, as in the case of sawdust saturated with linseed oil. The cause referred to is, according to the writer's experiments, oxydation of the oil.

Combustion, so far as we have to consider it, is in this case the rapid union of a substance with oxygen with the presence of a flame. There can be, of course, repeated oxydation without flame, but if the action be sufficiently repeated, heat enough will be generated to set the substance on fire. Then if a considerable quantity of inflammable vapor be present, an explosion is likely to follow.

To furnish an oil which shall resist the relatively large quantity of highly heated oxygen (at a pressure of 45 lbs., three times as great on a given surface as at the pressure of the air), is a matter which requires special study and facilities.

We have made a special study of the requirements of an oil which shall reduce the chances of the possibility of spontaneous combustion to a minimum, and where such facts have been present, by the use of our material, a great deal of this serious difficulty has been avoided.

Should any of your subscribers wish to correspond with us further regarding this matter, we would be very glad to do so.

To sum up: Use an oil as little likely to spontaneous combustion as it is possible to secure it. Have as few places where the oil can lodge in the machine as possible; in other words, have as few joints and as few turns in your pipes as it is possible to have, as it is a well known fact that where air strikes a surface in turning past a joint or elbow, friction is the result.

It is also very necessary to avoid the free use of oil. Use just as little as possible. There is a strong tendency on the part of engineers to use too much oil, simply because they want to be sure of having enough—on the principle that it is better to have too much than too little.

In this month's COMPRESSED AIR we find another article bearing on this same subject, and the writer begs leave to say, that "to our minds, it is a very unsafe thing to attempt to cleanse a cylinder with soft soap and water, unless an abundance of water is used after the operation to cleanse the cylinder very thoroughly."

Kerosene is still more dangerous; so the only safe method to pursue (to our minds) is to use oil as little liable to carbonize as

possible, and to remove and clean the valves at short intervals.

We feel that our experience in the manufacture of a suitable lubricant will at least justify the consumer in making a few experiments. Very truly yours,

FISKE BROTHERS REFINING CO.

The Hogan Water Tube Boiler.

There is before us a tabulated report of a ten hours' test run of two Hogan Water Tube Boilers (manufactured by the Hogan Boiler Co., of Middletown, N. Y.), in operation at Jerome Park Reservoir, Fordham, New York city, the figures of which so greatly impress us that we think they will interest the readers of COMPRESSED AIR, together with some deductions therefrom.

The test was made by Messrs. Younglove and Vreeland, of Sibley College, Ithaca, N. Y., under the auspices of the Faculty of the College; the ends sought by the promoters of the test being purely educational and scientific.

These boilers, aggregating 550 H. P., were put to work in 1896, one in March, the other in August of that year. They had been in continuous use, and they were tested at every-day working pressure.

The machinery plant consists of one Duplex Corliss Condensing Air Compressor.

There was burned in the ten hours' run, 9284 pounds of ordinary bituminous coal. Per pound of dry coal the boilers showed an evaporation of 9.11 pounds of water, or from and at 212° an evaporation of 10.71 pounds of water; the equivalent evaporation from and at 212° was 11.95 pounds of water per pound of combustible.

The efficiency shown was 78.1 per cent. The average steam pressure was 116.5 pounds.

These figures throughout show high economy; but it is not until we take into consideration the conditions under which the test was made, that the high results obtained are made manifest.

As before stated, one of these boilers had been in continuous service 14 months, the other 8 months. This and the fact that they were taken in hand by the experts in their everyday working condition and were fired with everyday working coal, gives additional emphasis to the foregoing figures. It is established custom preliminary to testing boilers to thoroughly clean them for soot and scale, no matter how short a time in use, and it is also customary, in order that high results may be had, to fire with selected coal. In this test, however, not only is it the fact that neither of these boilers were given any attention prior to the test being instituted as to their internal condition, whether for scale or soot; and, moreover, it is the further fact that they had not been cleaned for scale, external or internal, at any time between the hours of the test and the dates upon which they were first fired, viz., one in March, 1896, the other in August, 1896.

It is equally true that they had never been treated with any sort of compound, or nostrum, for the prevention of scale accumulation.

We have every reason for knowing that the high efficiency shown by these boilers in April under this test is still preserved; and inasmuch as no loss of efficiency had resulted through their taking on scale in the periods in which they had been at work, it is reasonable to conclude that they never will lose in efficiency from that cause.

The percentage of moisture in steam was 2.1 per cent. at engines, which were 75 ft. from boilers.

Mr. Harlan P. Wellman, of the Ashland & Catlettsburg Railway Co., Ky., has recently patented various attachments for electric railway cars, embodying the use of compressed air. One device is intended to effect the automatic lowering of a trolley pole in the event of the wheel jumping the trolley wire. The wheel being automatically brought to a line beneath the trolley wire, re-engagement with the latter can be readily accomplished.

Another device patented by Mr. Wellman contemplates enabling the reversal of the position of the trolley pole without requiring an attendant to leave the car.

In all these forms the inventor stores the compressed air in a reservoir beneath the car, from which it is led to suitable mechanism on the car roof, this mechanism being the embodiment of simplicity.

PNEUMATIC APPLIANCES.

PATENTS GRANTED AUGUST, 1897.

Specially prepared for COMPRESSED AIR from the Patent Office files by Grafton L. McGill.

588,246.—Air Compressor. Ira H. Spencer, Hartford, Conn. Assignor to the Spencer Motor Co., same place.

An air compressor embracing a piston cylinder, a valve-actuating member carried by the piston, and a water-distributing apparatus having two annular chambers located one within the other. The outer chamber is divided radially and transversely to form water-way compartments, one of which constitutes an exhaust compartment and communicates with the interior of the valve-chamber, another of which communicates with the cylinder and the interior of the valve-chamber, while a third communicates with the interior of the valve chamber, and has a supply-inlet. The outer chamber also has two independent water-ways controlled by the movements of a valve for effecting communication between the middle portion and opposite end portion, alternately, of the valve-chamber. A rotary reciprocatory valve is provided for alternately establishing communication between the water-supply compartment and the outer cylinder, and the opposite ends of the valve-chamber. It is formed with ports and a suitable flange for cutting off and establishing, alternately, communication between the piston cylinder and the water-supply compartment. Suitable means, designed to be controlled by the strokes of the piston, are employed for effecting alternately opposite rotative movement of the valve.

588,509.—Hot-Air Motor.—William Trewhella, Trentham, Victoria. Assignor to the Trentham Engineering Company, Limited, same place.

The inventor provides, in a hot-air engine, a vertical power-cylinder, having a combustion chamber in the lower part thereof; two pistons working in said cylinder, an exhaust duct leading to the combustion chamber, and a valve for such duct. A regenerator is interposed between this valve and the combustion chamber, and a cold-air pipe leads from the space between the regenerator and the exhaust valve to about the centre of the power cylinder. A suitable governor for controlling the exhaust valve, and means for imparting relative movements to the pistons are also employed.

589,190.—Apparatus for Compressing Air. —Edwin C. Nichols, Topeka, Kansas.

In a compressed air apparatus is employed a conductor, comprising a hollow wheel having a hollow, perforate crank-wrist, a hollow shaft having openings within the wheel, and a compressed air conductor connected with the crank-wrist. A wheel is located at each end of a sluice, and horizontal air-conducting pipes having closed ends are journaled upon the crank-wrist and connect the wheels at opposite ends of the sluice. A water energized air-compressor is located within the sluice and has induction pipes connected with the horizontal air-conducting pipes on the wheel.

588,825. — Pneumatic Water-Elevator. — John Haas, Chicago, Ill.

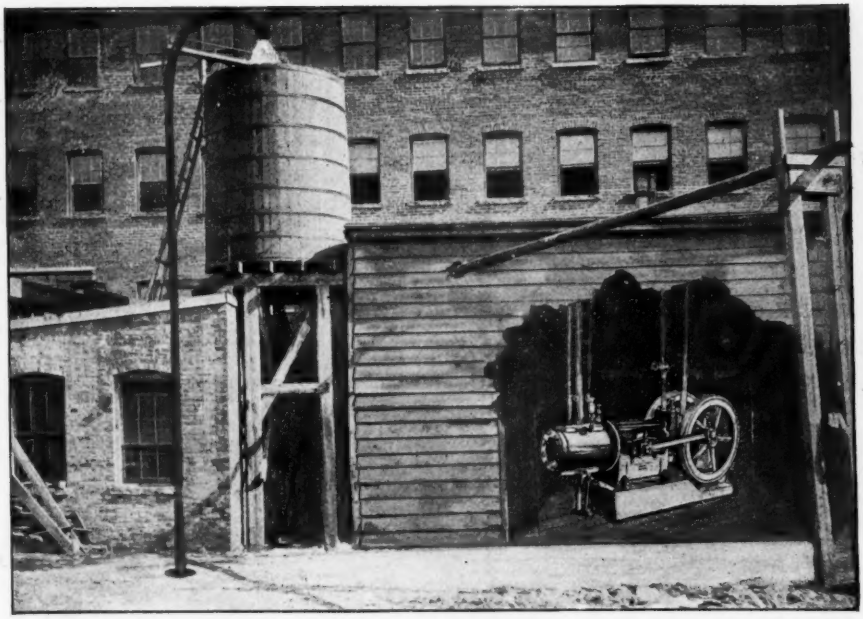
A pneumatic water-elevator, embracing a water pipe, an air pump, and a pipe connected with said pump, and having one end communicating with the interior of the water-pipe near the lower end thereof. A valve for regulating the passage of air in the air pipe is conveniently located A tank or receptacle into which the water pipe opens is provided with an outlet or discharge pipe for the water, and a perforated plate or diaphram is arranged across the interior of this tank at one side of the discharge spout. A pipe connects the upper portion of this tank with the air pump.

588,908.—Pneumatic Conveyor.—Arthur P. Heslop, Anaconda, Mont.

In connection with a casing having inlets for air and a discharge pipe leading therefrom, the inventor employs a hollow hub rotatably mounted in said casing and fan-blades projecting from said hub; the latter being divided into a plurality of chambers. A discharge pipe extends outwardly from each of said chambers and a feed-pipe delivers material into the hollow hub.

587,704.—Valve for Air or Gas Compressors, &c.—James Clayton, Brooklyn, N. Y.

This invention comprises a poppet-valve having a valve-head and a main guiding stem. A facing disk fitted to the valve-head is provided with a plurality of stems which pass through holes in said head and are loosely secured thereto outside of the main stem. An elastic cushion is located between the head and facing disk.



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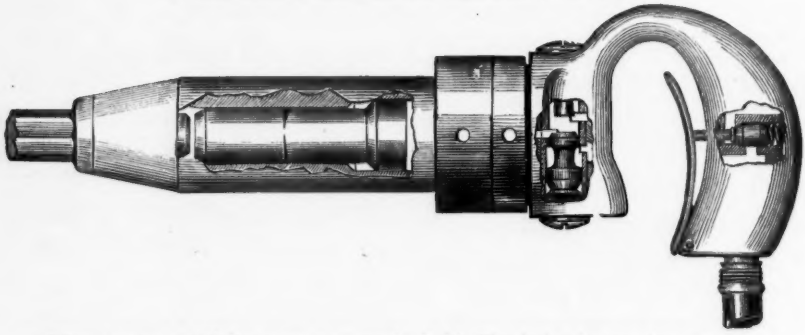

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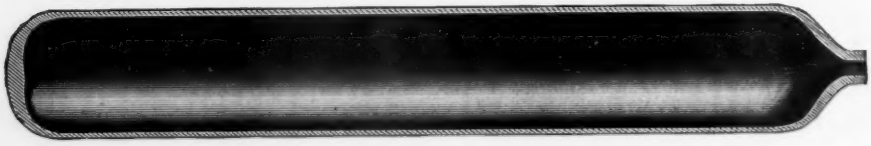

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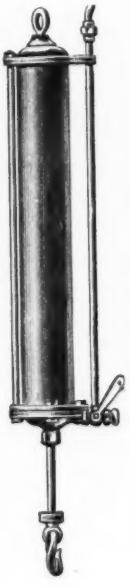

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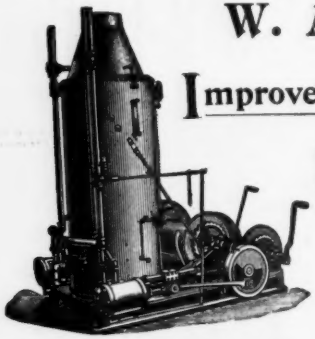

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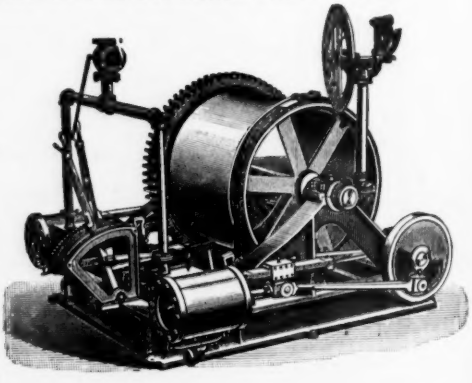

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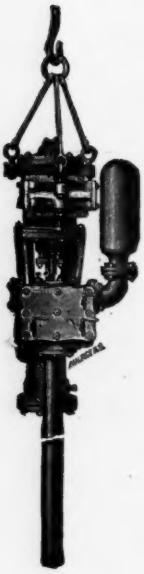

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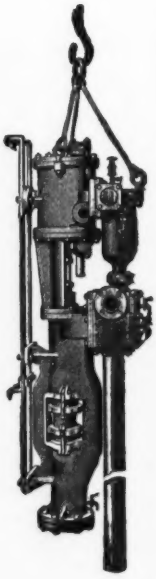

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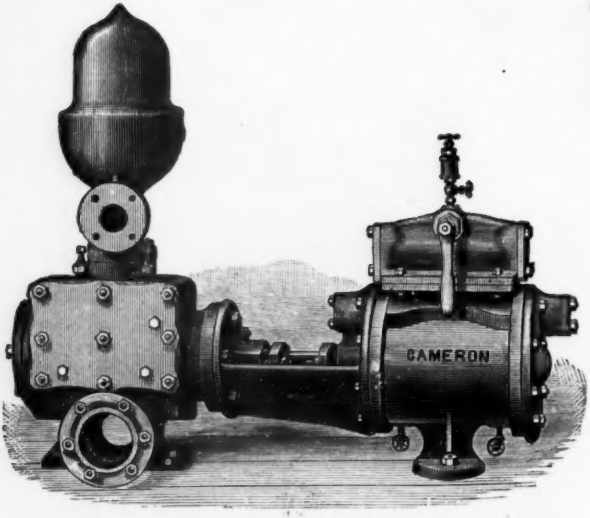

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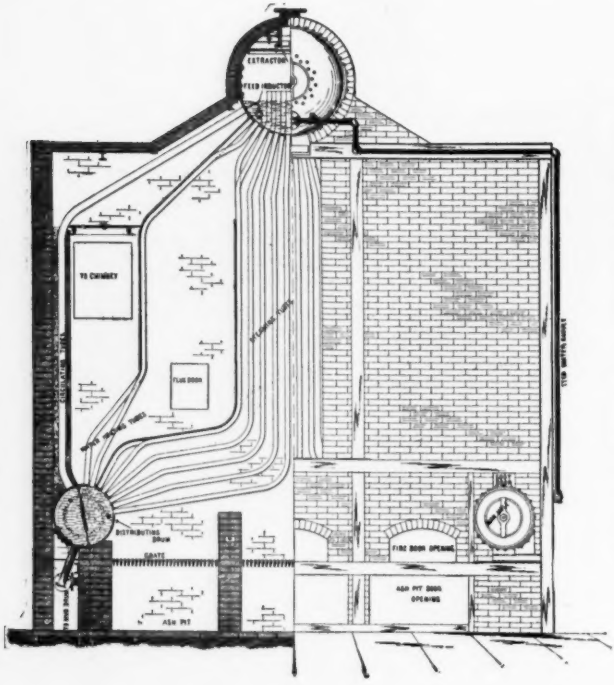

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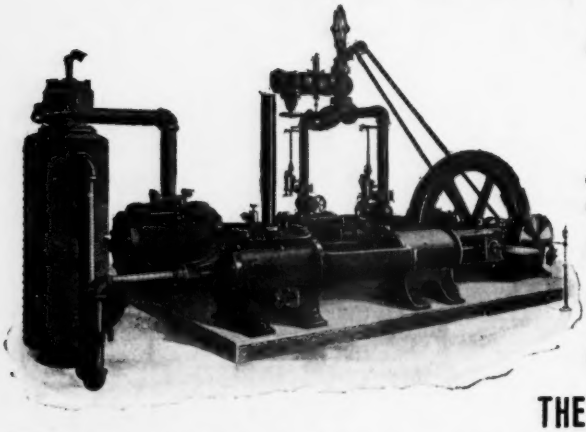

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